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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53 (c).

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TITLE OF THE INVENTION (280 characters max)

THREE-PLATE MICRO CAPACITIVE PRESSURE SENSOR

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ENCLOSED APPLICATION PARTS ***(check all that apply)***

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☒ Application Data Sheet. See 37 CFR 1.76

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METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT *(check one)*

☒ Applicant claims small entity status. See 37 CFR 1.27.

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The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

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Respectfully submitted,

SIGNATURE [signature]

Date [12-4-03]

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Docket Number: [2500-000019]

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

PROVISIONAL APPLICATION COVER SHEET

Additional Page

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Number 2 of 2

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Three-plate Micro Capacitive Pressure Sensor

2.1 Field Of The Invention

The invention relates to micro capacitive pressure sensors in the general field of Microelectromechanical Systems (MEMS).

2.2 Background Of The Invention

Pressure sensing is one of the most established areas of sensor technology [1]. One specialised application of pressure sensors is hydrostatic tank gauging (HTG) [2]. HTG is a pressure-based tank gauging system that uses a combination of pressure and temperature measurements to provide a totally automated, multiple measurement system for liquid inventory measurements. Traditional HTG installations involve disrupting the integrity of the tank wall in three or more places to mount multiple pressure and temperature sensors [3]. Each sensor is a complex combination of electrical and mechanical components. MEMS technology offers a means of eliminating the need for multiple sensors as it allows on-chip integration of pressure and temperature transducers [4].

While there is a potential for combining various sensors and signal conditioning circuit into one microelectromechanical system, silicon micromachined capacitive pressure sensor such as those described in US Patent No 6631645, 6051853, 6122973 and 6595064 are not suitable for hydrostatic measurements. The reason for this is pressure sensors for HTG systems must be able to withstand the large pressure inside the tanks and be sensitive to the relatively small pressure changes brought about by variations in the fluid head. In micro capacitive pressure devices, the flexible diaphragm serves as one electrode of a capacitor, whereas the other electrode is located on a substrate beneath it. As the diaphragm deflects in response to the applied pressure, the average gap between the electrodes changes, leading to a change in the capacitance [5]. For capacitive pressure sensors to operate in a high pressure environment, the movable plate must be thick. The trade-off introduced by the use of a thick diaphragm is low sensitivity to small changes in pressure. Consequently, a parallel plate capacitive pressure sensor would not be capable of detecting the relatively small pressure variations in a high pressure environment. The purpose of this invention is to provide a micro capacitive pressure sensor for HTG.

2.3 Objects Of The Invention

The present invention is intended to achieve a pressure sensing device that is able to accurately measure small pressure variations in the presence of a large constant load.

The problem solved by the present invention is the lack of sensitivity brought when the diaphragm thickness is increased in order to withstand high pressures.

The main application is in hydrostatic tank gauging (HTG) systems. It is an emerging way to accurately gauge liquid inventory and to monitor transfers in tank farms and similar multi-tank storage facilities. Increasingly, HTG systems are also employed for storage tank leak detection. The interest in pursuing better leak detection and prevention methods is prompted by concerns for environmental protection, coupled with increasingly stringent legislation and regulation.

The pressure-capacitance relationship of the device is non-linear, but smart sensor technology can be used to compensate for non-linear behavior with minimal or no user intervention.

2.4 Summary Of The Invention

This invention is a micro capacitive pressure sensor for hydrostatic tank gauging (HTG), an emerging way to accurately gauge liquid inventory and to monitor transfers in tank farms. Since industrial storage vessels are huge, the sensing element must be able to withstand the large pressure, and yet be sensitive enough to detect the relatively small pressure changes brought about by variations in the fluid head. To achieve these apparently conflicting requirements, a novel three-plate structure is proposed

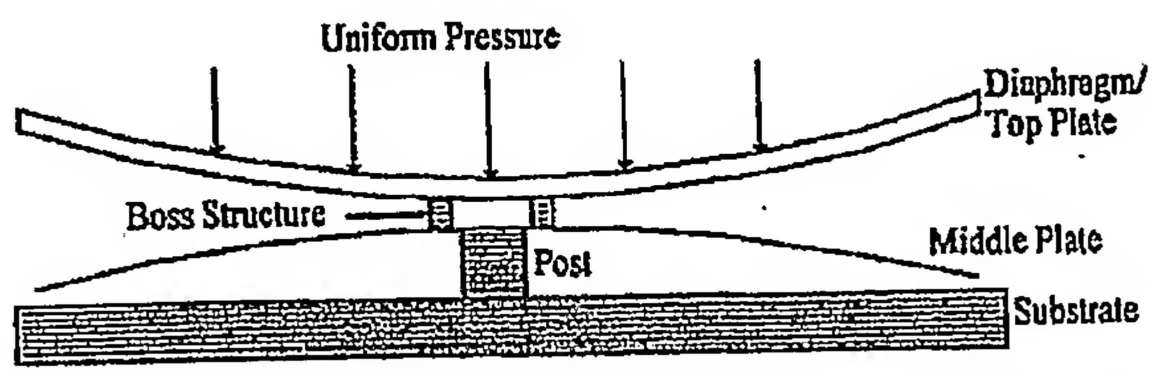

Figure 1 : Schematic diagram of proposed MEMS pressure sensor.

2.5 Detailed Description Of The Preferred Embodiments

The micro capacitive pressure sensor for detecting small pressure changes in the presence of a large constant load comprises of three parallel plates (See Figure 1). As in typical parallel plate capacitive pressure sensors, one of the plates is the diaphragm while the second plate is the silicon substrate. In order to withstand the high pressure, the diaphragm must be thick so it will not rupture. A thin plate, referred to as the middle plate, is placed between the diaphragm and the device substrate. It is a free standing structure supported only at the centre by a post. When pressure is applied, the diaphragm will deflect. Beyond a pre-determined threshold pressure, a boss ring etched below the thick diaphragm will come into contact with the middle pate and cause it to deflect. Pressure is measured by monitoring the change in capacitance between the middle plate and the silicon substrate. Since the middle plate is a cantilever, it magnifies the small deflections in the thick diaphragm and thus enabling small changes in pressure to be detected.

The steps for fabricating the device using surface micromachining techniques are as follows :-

Step 1 : A 1000 µm x 1000 µm x 2.5 µm sacrificial silicon dioxide layer is laid on a n-type silicon wafer that is coated with a 0.3 mm nitride layer. The silicon dioxide layer defines the air gap between the bottom and the middle plates. By patterning and etching the silicon dioxide layer, a 40 µm x 40 µm hole is formed so that the post for supporting the middle plate can be fabricated (Refer to Figure 2).

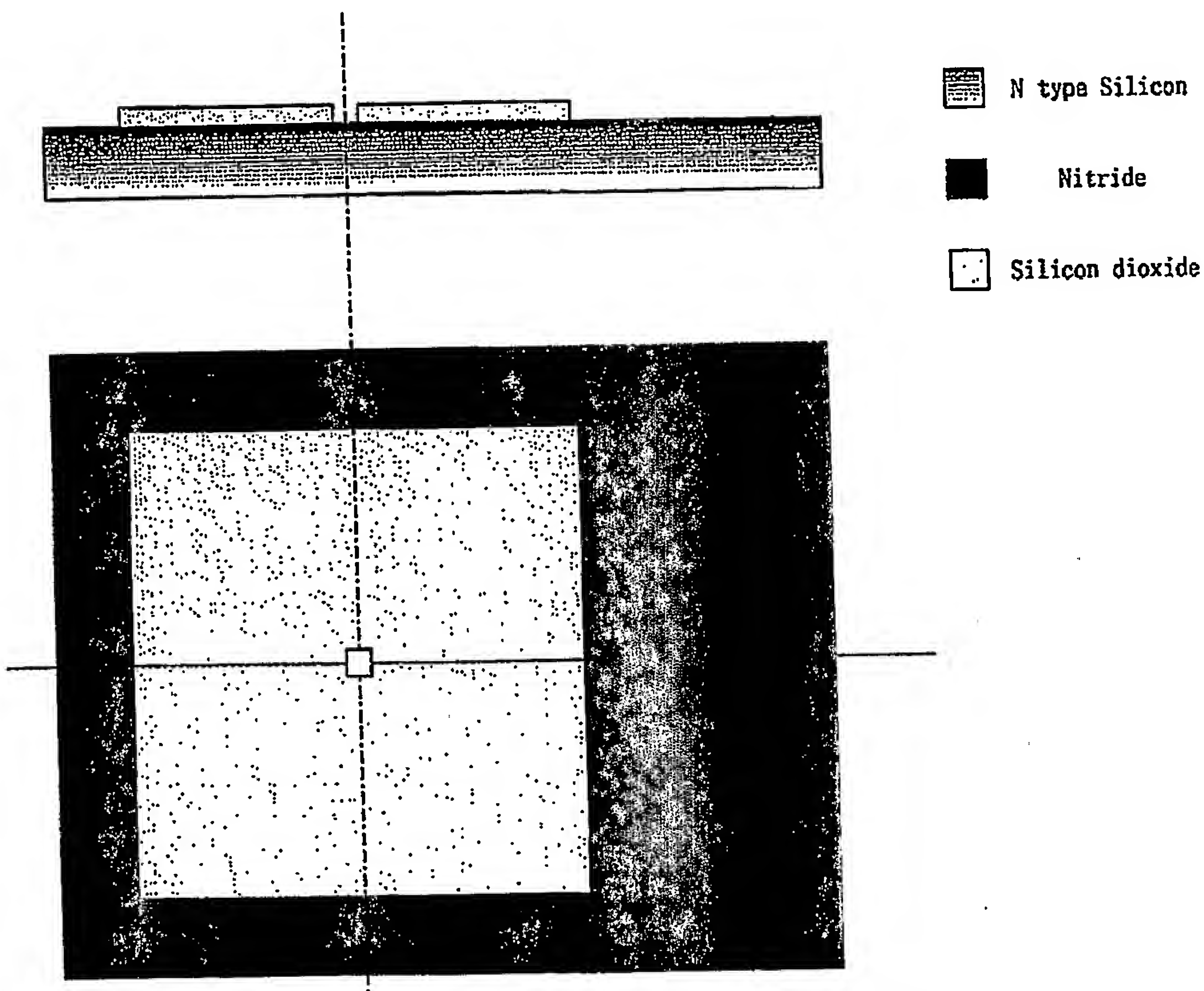

Figure 2 :. Deposit and pattern first silicon dioxide sacrificial layer

Step 2 : A 2.0 µm thick low tensile stress polysilicon layer is deposited to form the first structural layer of the 3-plates micro capacitive pressure sensor. The center square in the diagram shown in Figure 3 is the middle plate while the lateral polysilicon encircling the center square and will form the stationary edges. Since the middle plate serves as an electrode of a parallel plate capacitor, electrical connection is provided in the form of a probe pad.

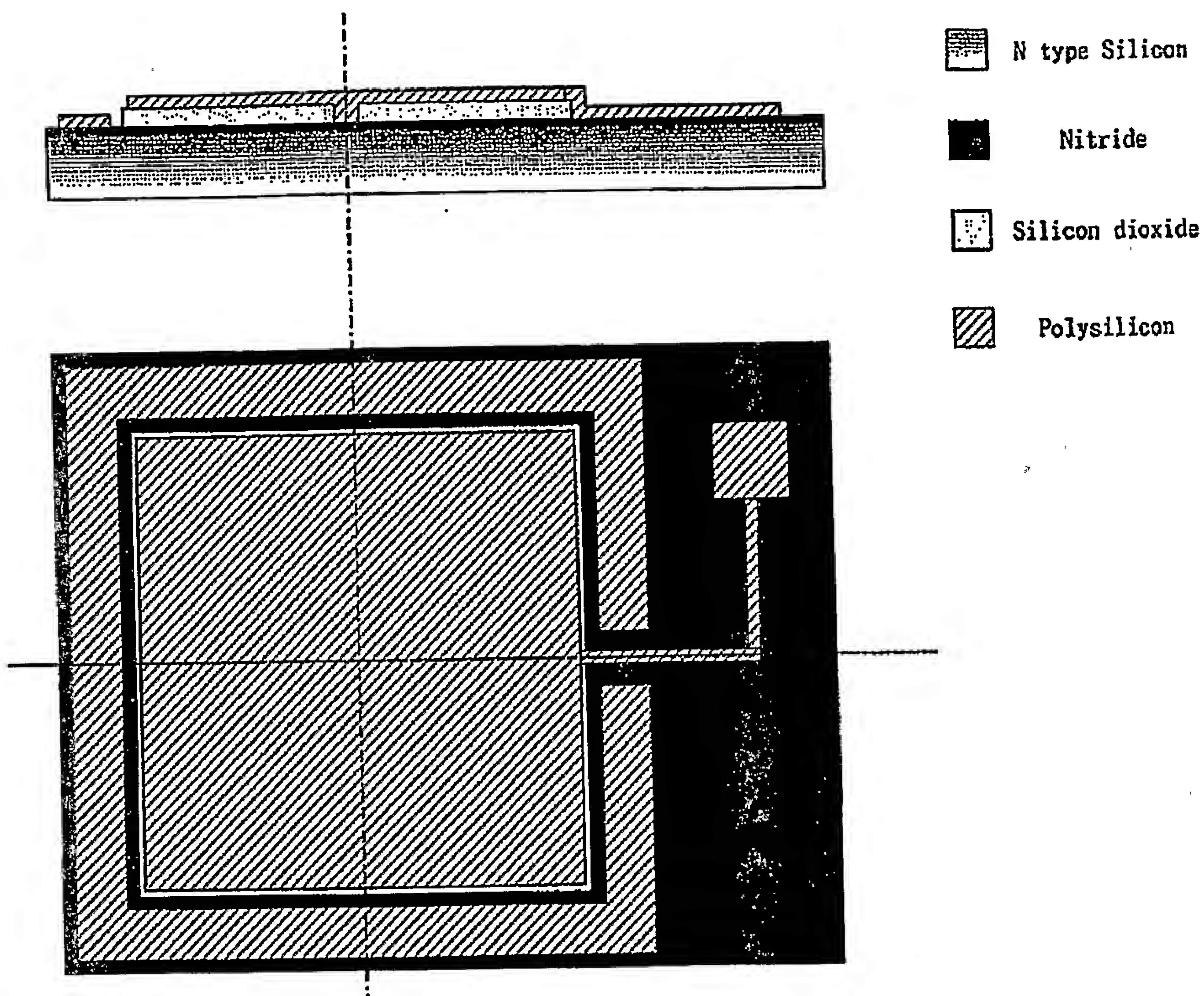

Figure 3. Poly 1 layer forms middle plate

Step 3 : A 6 μm layer of silicon oxide is then deposited on the low stress polysilicon structural layer (Poly 1) formed in Step 2. This silicon oxide layer defines the gap between the top plate and middle plate. Using a mask to pattern and etch the second silicon oxide layer, a 1100 μm ×1100 μm square oxide layer that defines the size of the sealed chamber is constructed (See Figure 4).

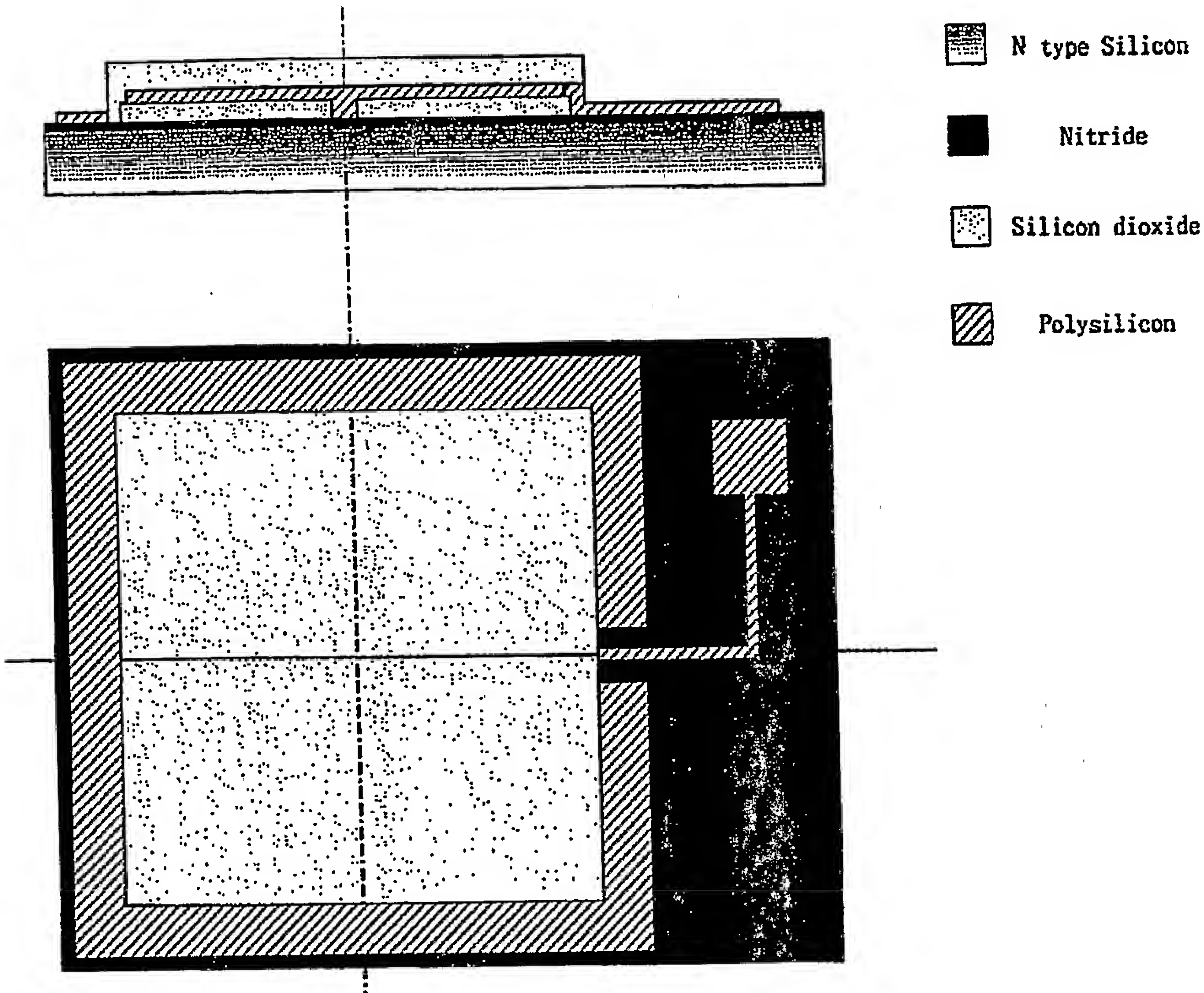

Figure 4. Second oxide layer forms the gap between the top and middle plates

Step 4 : To construct the boss ring, the second silicon oxide layer is patterned. As shown in Figure 5, a square ring at the center of the oxide layer center is removed to leave behind a small indentation. The indentation is used to form the boss ring structure under the top plate. The touch point pressure can be controlled by changing the depth of the indentation.

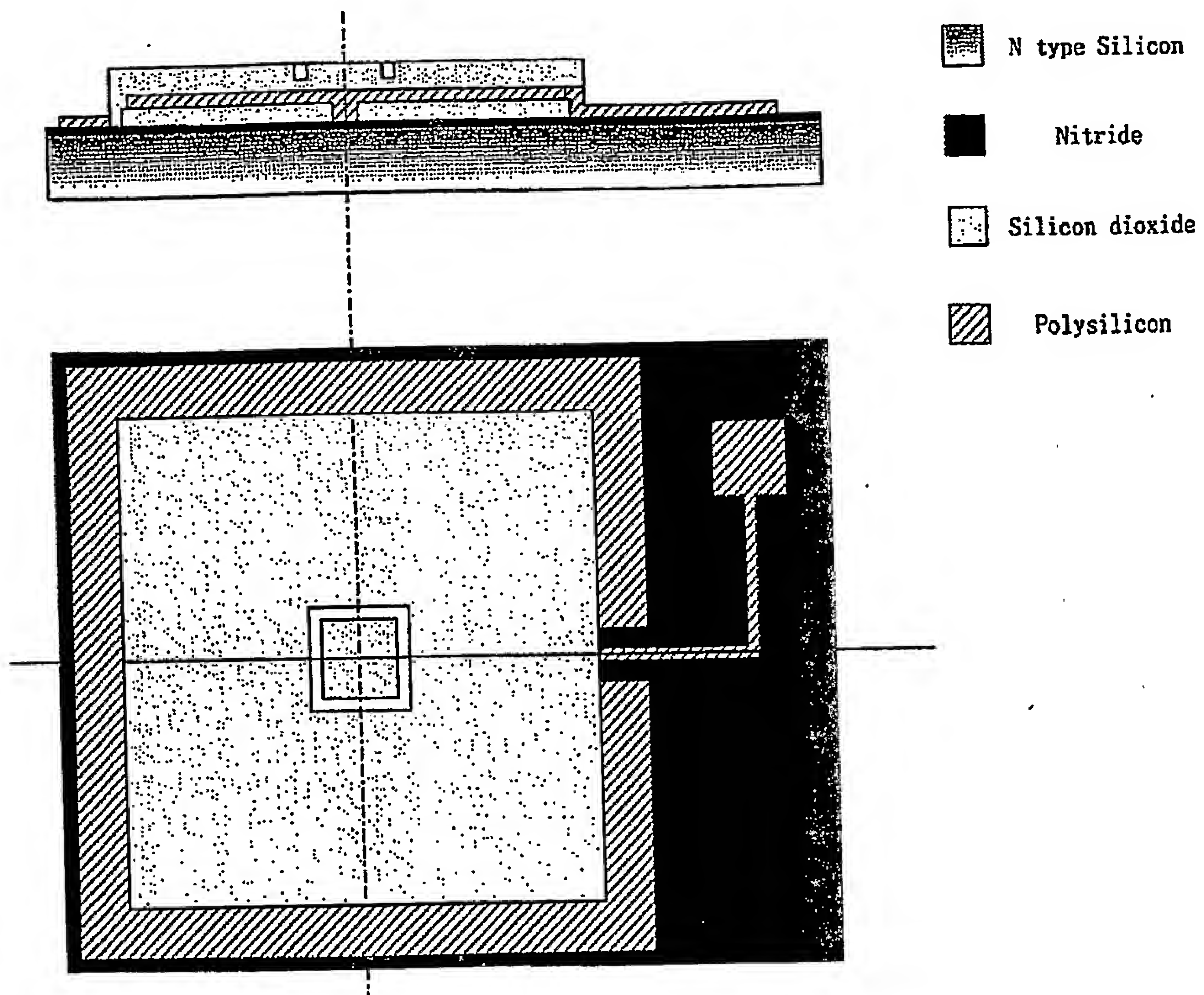

Figure 5. A square ring at the center of the second oxide layer

Step 5 : A 0.3 µm layer of low stress nitride is deposited to provide an isolation layer between the top and middle plates. Since the nitride fills the indentation fabricated in Step 4, an electrical isolation will exist when the top plate comes into contact with the middle plate. Next, the nitride layer at the probe pads are etched away to produce the structure shown in Figure 6.

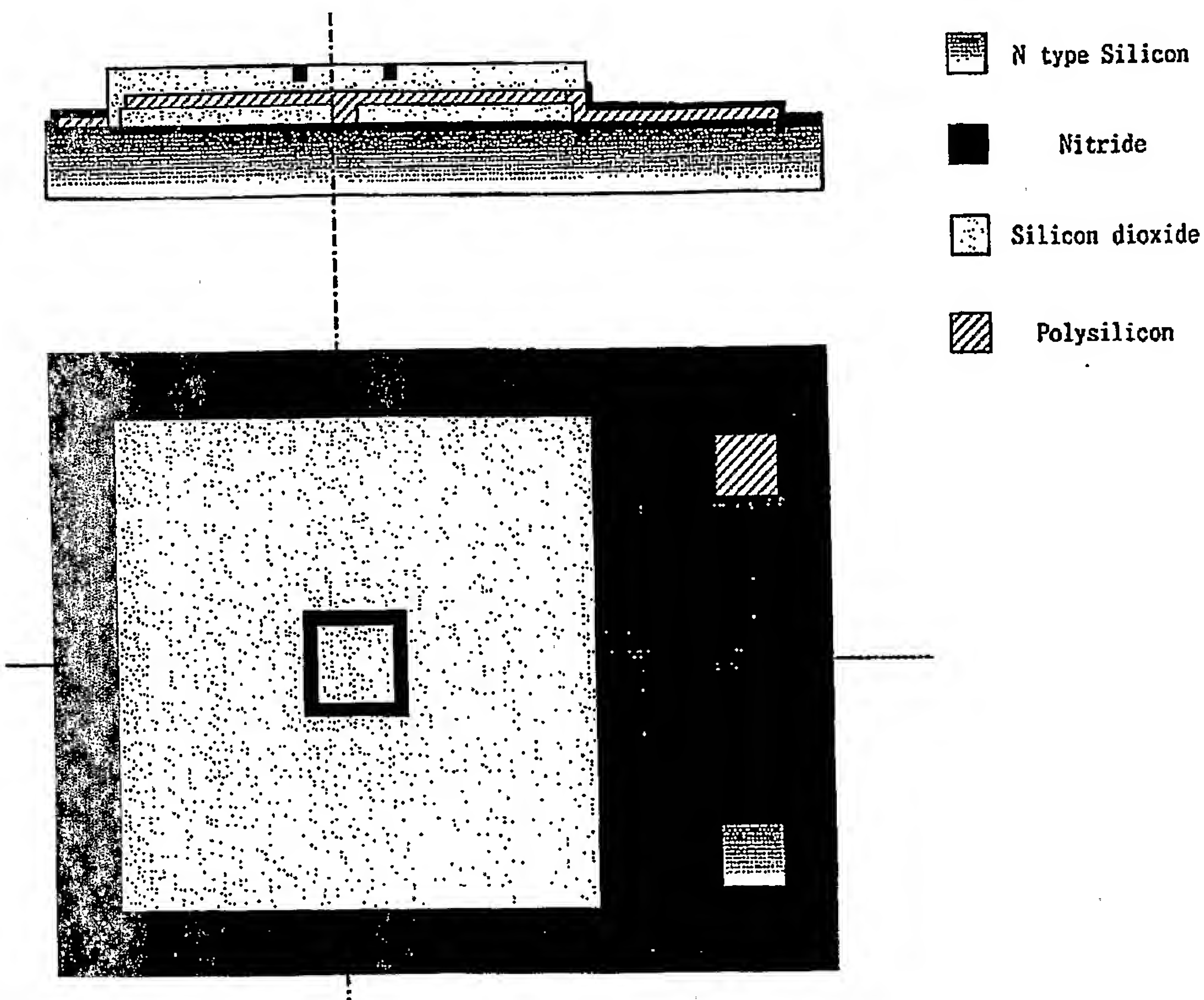

Figure 6 : A 0.3 µm nitride layer is deposited and patterned

Step 6 : As shown in Figure 7, a 20 μm thick polysilicon layer (Poly 2) is deposited and patterned. Poly 2 is the top plate of the device which serves as the pressure sensing diaphragm. It also forms a sealed chamber between top plate and substrate.

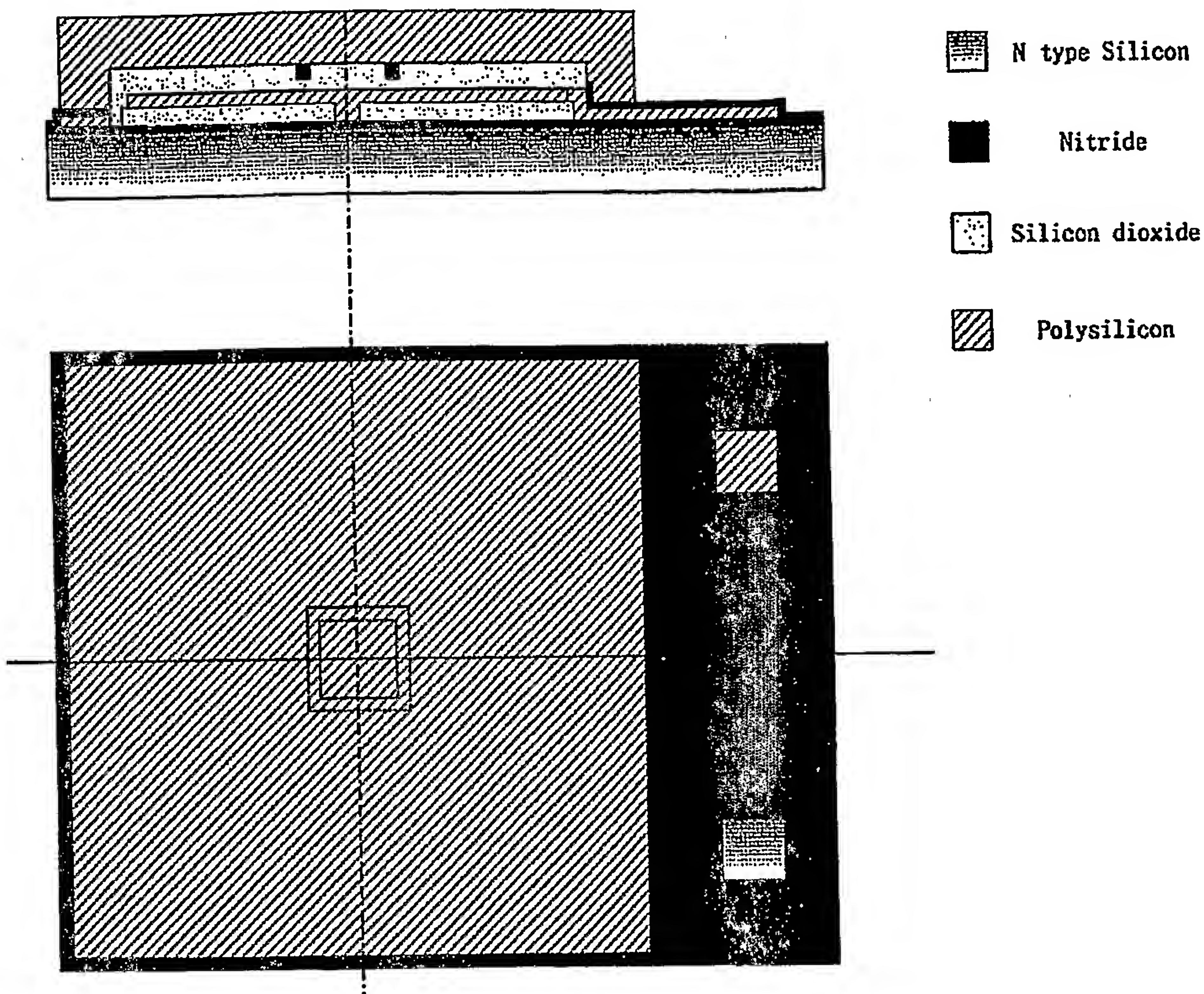

Figure 7 : A second polysilicon layer forms the top plate and fixed edges

St p 7 : Small through holes are etched at the backside of the silicon wafer. Then, the structures are released by immersing the device in a 49% HF solution. The small holes may be used provide a means for controlling the reference pressure in the chamber.

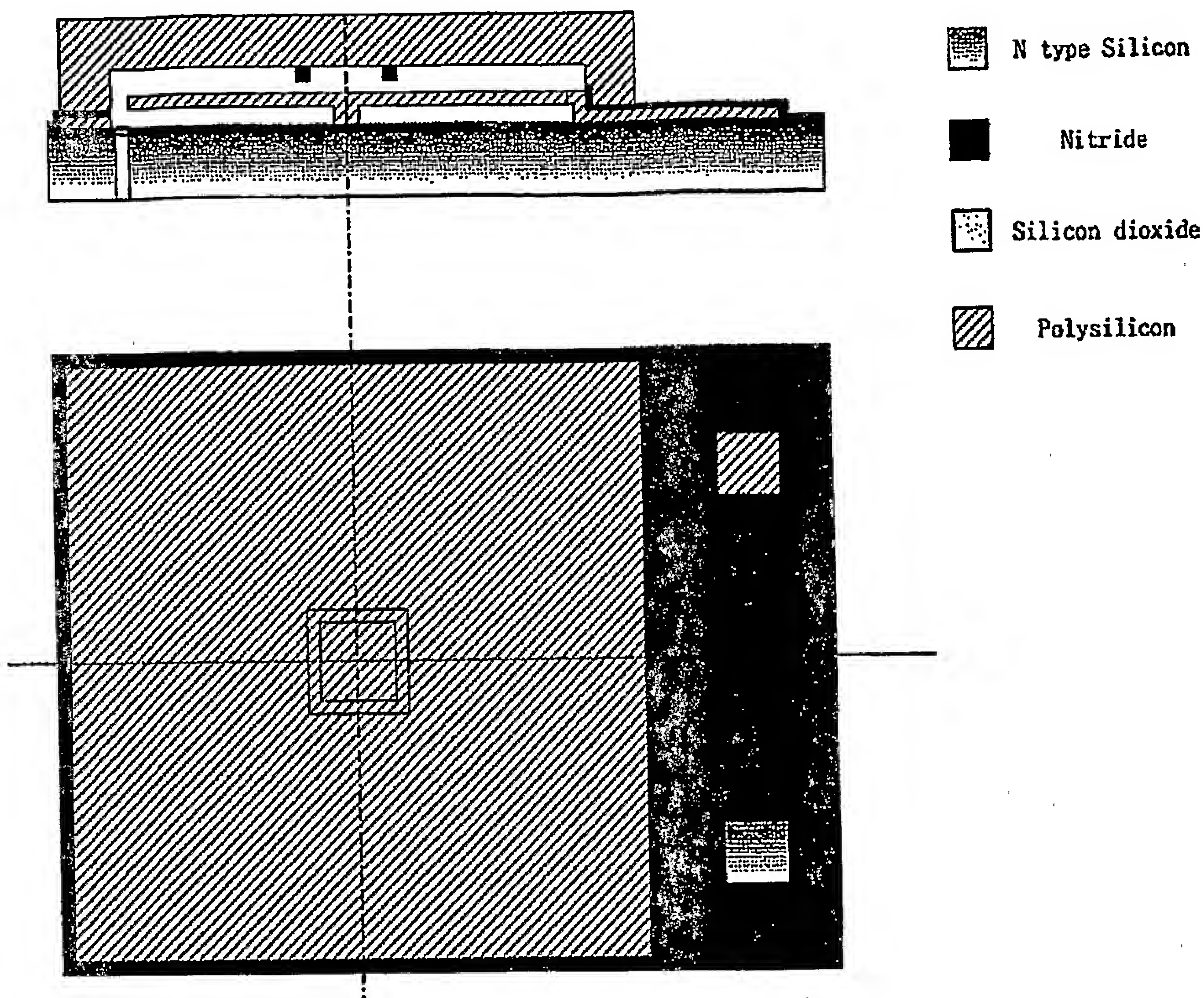

Figure 8 : A small etch hole at the backside of the wafer

Step 8 : Metal (Al or Au) with a thin adhesion layer is deposited by lift-off patterning. The side wall of the photoresist is sloped at a reentrant angle, which provides breaks between the metal deposited on the surfaces of probe pads and that on the photoresist. The photoresist and unwanted metal (atop the photoresist) are then removed in a solvent bath. Figure 9 shows the final structure.

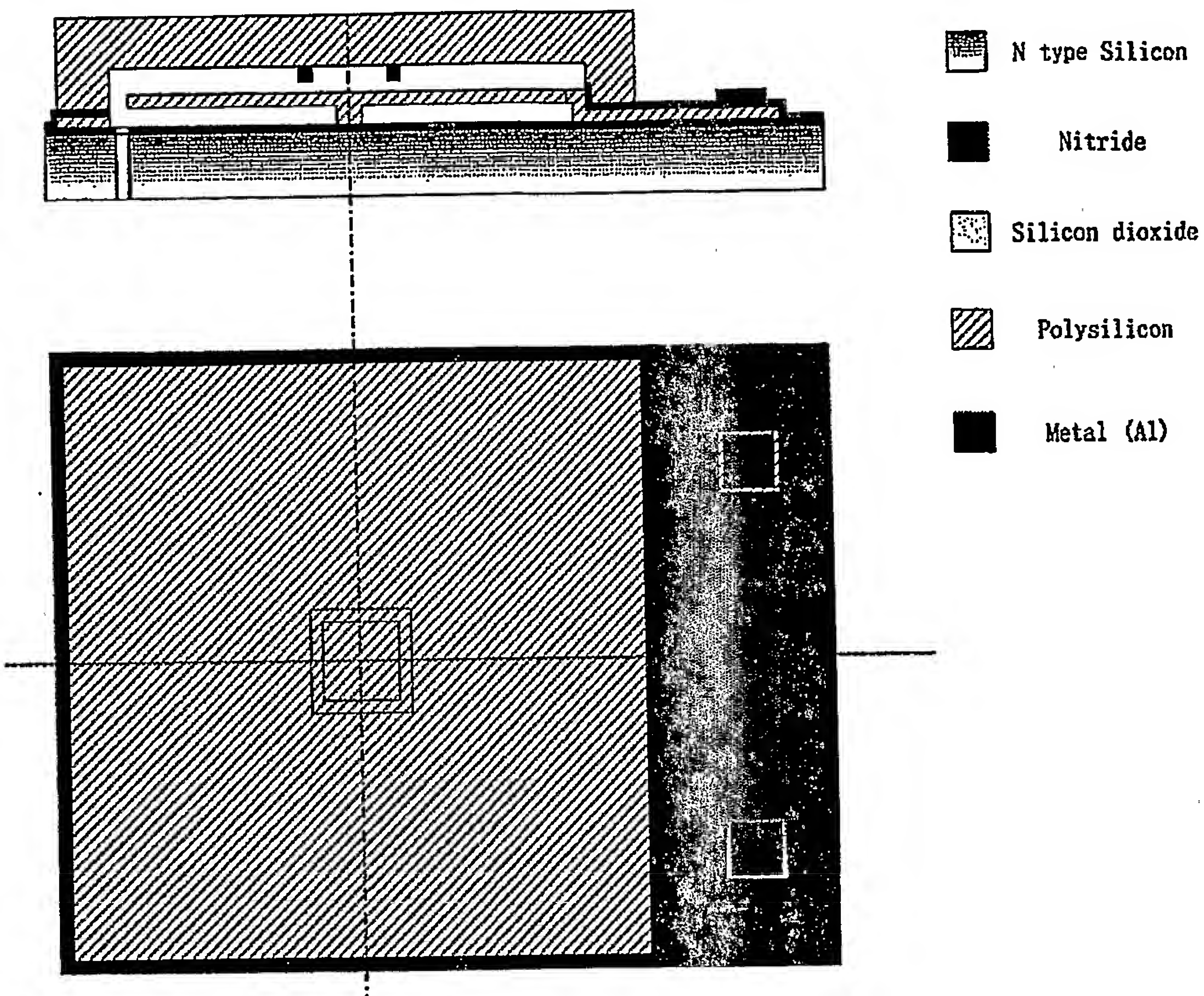

Figure 9 : Metallization

2.6 <u>Modifications Of The Preferred Embodiments</u> (if any)

Another application for the invention can be in tactile sensing. Tactile sensing is essential for human beings and very useful for robot motion control. The tactile organs in humans have high precision and high resolution, and contribute to dexterous motion of the human hand. The criteria for these tactile sensors are precision, high resolution and the ability to cover narrow surfaces [5]. Binary switch-type tactile sensors are generally used in robotic applications because of their simplicity and robustness. However, it is impossible for such types of sensors to sense the magnitude of the contact force, since a binary switch sensor has only one pressure threshold. The invention may be used for tactile sensor in humanoid robots or artificial limbs because it provides high sensitivity around a pre-determined threshold value.

2.7 References and Prior Art

- List of references cited in this write-up.

[1] C. Ajluni C, Low-pressure sensor opens wide applications frontier, Electronic Design, Vol. 44, pp. 59-64, 1996.
[2] G. Vass, "The Principles of Level Measurement", *Sensors*, Vol. 17, pp. 55-64, 2000.
[3] J.G. Webster, "The measurement, instrumentation, and sensors handbook", CRC Press, 1998.
[4] K. Kasten, J. Amelung, W. Mokwa, "CMOS-compatible capacitive high temperature pressure sensors", *Sensors and Actuators*, Vol. 85, pp. 147-152, 2000.
[5] M. Gad-el-Hak, "The MEMS handbook", CRC Press, 2001.
[6] R. Tajima, S. Kagami, M. Inaba and H. Inoue, "Development of soft and distributed tactile sensors and the application to a humanoid robot", *Advanced Robotics*, Vol. 16, No. 4, pp. 381–397, 2002.

- List of prior art searches(patents and non-patent literature) relevant to the invention.

[1] US Patent No 6631645, "Semiconductor pressure sensor utilizing capacitance change", 2003

[2] US Patent No 6051853, "Semiconductor pressure sensor including reference capacitor on the same substrate", 2000.

[3] US Patent No 6122973, "Electrostatic capacity-type pressure sensor with reduced variation in reference capacitance", 2000.

[4] US Patent No 6595064, "Capacitive pressure sensor", 2003

Patents related to HTG but sensing method is not the same as our invention

[5] US Patent No. 4,335,608 "Submersible pressure transducer device", 1982.

[6] US Patent No. 4,804,944 "Hall effect liquid level sensing apparatus and method" 1989.

[7] US Patent No 5,115,679 "Level measuring bubbler tube tip", 1992.

[8] US Patent No 5,309,764 "Tank gauging system", 1994.

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